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CATACLYSMIC THEORIES OF GEOLOGICAL CLIMATE.

[*Extracted from the* GEOLOGICAL MAGAZINE, September, 1878.]
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ON THE ARGUMENT FOR THE AGE OF THE EARTH AS DETERMINED BY TIDAL RETARDATION.*

BY JAMES CROLL, LL.D., F.R.S.,
OF THE GEOLOGICAL SURVEY OF SCOTLAND.

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[1] Read before the Geological Society of London, May 8th, 1878.

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CATACLYSMIC THEORIES OF GEOLOGICAL CLIMATE.[1]

By James Croll, LL.D., F.R.S.,

of the Geological Survey of Scotland.

THE most important geological problem, and the one of all others which at present excites the greatest attention, is the cause of those extraordinary changes of climate which have taken place during past ages. How are we to account for the cold and Arctic condition of things which prevailed in temperate regions during what is called the Glacial Epoch, or for the warm and temperate climate enjoyed by the Arctic regions, probably up to the Pole, during part of the Miocene and other periods? Theories of the cause of those changes, of the most diverse and opposite character, have been keenly advocated, and one important result of the discussions which have recently taken place is the narrowing of the field of inquiry and the bringing of the question within proper limits.

At one time Lyell's theory of the relative distribution of land and water was generally regarded by geologists as sufficient. It is, however, now generally admitted to be wholly insufficient to explain the now-known facts, and the conviction is becoming almost universal that we must refer the climatic changes in question to some cosmical cause.

The theory of a change in the obliquity of the ecliptic has been appealed to. This theory for a time met with a favourable reception, but, as might have been expected, it was soon abandoned. The researches of Mr. Stockwell of America, and of Mr. George Darwin and others in this country, have put it beyond doubt that no probable amount of geographical revolution could ever have altered the obliquity to any sensible extent beyond its present narrow limits. It has been demonstrated for example, by Mr. George Darwin, that supposing the whole equatorial regions up to lat. 45° N. and S. were sea, and the water to the depth of 2000 feet were placed on the Polar regions in the form of ice—and this is the most favourable redistribution of weight possible for producing a change of obliquity—it would not shift the Arctic circle by so much as an inch!

[1] Read before the Geological Society of London, May 8th, 1878.

Variations in the obliquity of the ecliptic having been given up as hopeless, geologists and physicists are now inquiring whether the true cause may not be found in a change in the position of the earth's axis of rotation Fortunately this question has been taken up by several able mathematicians, among whom are Sir William Thomson,[1] Professor Haughton,[2] Mr. George Darwin,[3] the Rev. J F. Twisden,[4] and others; and the result arrived at ought to convince every geologist how hopeless it is to expect aid in this direction.

Mr. George Darwin has demonstrated that in order to displace the pole merely 1° 46′ from its present position, $\frac{1}{20}$ of the entire surface of the globe would require to be elevated to a height of 10,000 feet, with a corresponding subsidence in another quadrant. There probably never was an upheaval of such magnitude in the history of our earth. And to produce a deflection of 3° 17′ (a deflection which would hardly sensibly affect climate) no less than $\frac{1}{10}$ of the entire surface would require to be elevated to that height. A continent ten times the size of Europe elevated two miles would do little more than bring London to the latitude of Edinburgh, or Edinburgh to the latitude of London. He must be a sanguine geologist indeed who can expect to account for the glaciation of this country, or for the former absence of ice around the poles, by this means. We know perfectly well that since the Glacial Epoch there have been no changes in the physical geography of the earth, sufficient to deflect the pole half-a-dozen miles, far less half-a-dozen degrees. It does not help the matter much to assume a distortion of the whole solid mass of the globe. This, it is true, would give a few degrees additional deflection of the Pole; but that such a distortion actually took place is more opposed to geology and physics than even the elevation of a continent ten times the size of Europe to a height of two miles.

Mr. Twisden, in his valuable memoir referred to, has shown even more convincingly how impossible it is to account for the great changes of geological climate on the hypothesis of a change in the axis of rotation. This conclusion has been further borne out by another mathematician, the Rev. E. Hill, in an article in the June Number of the Geological Magazine. And Professor Haughton, in a paper read before the Royal Society, April 4th, and published in *Nature*, July 4th, entitled, "A Geological Proof that the Changes of Climate in Past Times were not due to Changes in the Position of the Pole," has proved from geological evidence that the Pole has never shifted its position to any great extent. "If we examine," he says. "the localities of the fossil remains of the Arctic regions, and consider carefully their relations to the position of the present North Pole, we find that we can demonstrate that the Pole has not sensibly changed its place during geological periods, and that the hypothesis of a shifting pole (even if permitted by mechanical considerations) is inadmissible to account for changes in geological climates."

[1] British Association Report, 1876 (part 2), p. 11.
[2] Proceedings of Royal Society, vol. xxvi. p. 51.
[3] Transactions of Royal Society, vol. 167 (part 1).
[4] Quart. Journ. Geol. Soc. February, 1878.

There is no geological evidence to show that, at least since Silurian times, the Atlantic and Pacific were ever in their broad features otherwise than they are now—two immense oceans separated by the Eastern and Western continents—and there is not the shadow of a reason to conclude that the poles have ever shifted much from their present position. On this point I cannot do better than quote the opinion recently expressed by Sir William Thomson:

"As to changes of the earth's axis, I need not repeat the statement of dynamical principles which I gave with experimental illustrations to the Society three years ago; but may remind you of the chief result, which is that, for steady rotation, the axis round which the earth revolves must be a 'principal axis of inertia,' that is to say, such an axis that the centrifugal forces called into play by the rotation balance one another. The vast transpositions of matter at the earth's surface, or else distortions of the whole solid mass, which must have taken place to alter the axis sufficiently to produce sensible changes of the climate in any region, must be considered and shown to be possible or probable before any hypothesis accounting for changes of climate by alterations of the axis can be admitted. This question has been exhaustively dealt with by Mr. George Darwin in a paper recently communicated to the Royal Society of London, and the requisitions of dynamical mathematics for an alteration of even as much as two or three degrees in the earth's axis in what may be practically called geological time shown to be on purely geological grounds exceedingly improbable. But even suppose such a change as would bring ten or twenty degrees of more indulgent sky to the American Arctic Archipelago; it would bring Nova Zembla and Siberia by so much nearer to the pole: and it seems that there is probably as much need of accounting for a warm climate on one side as on the other side of the pole.[1] There is in fact no evidence in geological climate throughout those parts of the world which geological investigation has reached, to give any indication of the poles having been anywhere but where they are at any period of geological time."[2]

In the memoir from which the preceding paragraph is quoted, Sir William maintains that an increase in the amount of heat conveyed by ocean currents to the Arctic regions, combined with the effect of Clouds, Wind, and Aqueous Vapour, is perfectly sufficient to account for the warm and temperate condition of climate which is known to have prevailed in those regions during the Miocene and other periods.

Now this is the very point for which I have been contending for upwards of a dozen years. The only essential difference between Sir William's views and mine is simply this: he accounts for an increase in the flow of warm water to the Arctic regions by a submergence of the circumpolar land, whereas I attribute it to certain agencies brought into operation by an increase in the excentricity of the earth's orbit. Such geological evidence as we possess of warm episodes in the polar regions does not point to such high temperatures

[1] This has been proved to be the case by Prof. Haughton, *Nature*, July 4, 1878.
[2] Trans. of Geol. Soc. of Glasgow, Feb. 22, 1877.

being specially due to submergence of the polar land. For taking the Miocene epoch as an example, all the way from Ireland and the Western Isles, by the Faroes, Iceland, Franz-Joseph Land, to North Greenland, the Miocene vegetation and the denuded fragmentary state of the strata point to a much wider distribution of polar land than that which now obtains in those regions. What has chiefly tended to retard the acceptance of the theory of secular changes of climate discussed in my work entitled "Climate and Time," is the fact that physicists have not fully realized to what an immense extent the climatic condition of our globe is dependent upon the distribution of heat by means of ocean currents. Were it not for the enormous amount of heat transferred from equatorial to temperate and polar regions by means of ocean currents, the globe would scarcely be habitable by the present orders of sentient beings. When this fact becomes fully recognized, all difficulties felt in accounting for geological climate will soon disappear. The climatic influence of ocean currents has not been sufficiently considered, owing doubtless to the fact that before I attempted to compute the absolute amount of heat conveyed by the Gulf Stream, so as to compare it with the amount directly received by the Atlantic from the sun, no one had ever imagined that that ocean in temperate and Arctic regions was dependent to such an extent on heat brought from the Equator.[1] And this being so, it was impossible for any one fully to realize to what an extent climate must necessarily be affected by an increase or a decrease of that stream.

Sir William Thomson speaks of his theory being that of Lyell; but beyond the mere assumption of the submergence of the circumpolar land the two theories have little in common. Indeed, no one who believes (as Sir William does) that the former warm climatic condition of the polar area was mainly due to a transference of heat from equatorial to Arctic regions by means of ocean currents can logically adopt Lyell's theory. According to that eminent geologist, the temperature of the Arctic regions was raised by the removal of the continents from polar and temperate regions to a position along the equator. But if the equatorial regions were occupied by land instead of water, the possibility of conveying heat to temperate and arctic regions by means of ocean currents was completely cut off. In fact, one of the most effectual ways of lowering the mean temperature of the globe would be to group the continents along the equator.

The surface of the ground at the equator becomes intensely heated by the solar rays, and this heat is radiated into space much more rapidly than it would from a surface of water warmed under the same conditions. Again, the air in contact with the hot ground becomes more speedily heated than it would if it were in contact with water, and consequently the ascending current of air over the equatorial lands carries off a greater amount of heat than it could have done from a water-surface. Now, were the heat thus carried

[1] Capt. Maury, of the U.S. Navy, was the first to call attention to the influence of the Gulf Stream on climate. Physical Geography of the Sea, 8th edition, 1860, p. 23.—Edit. Geol. Mag.

off to be transferred by means of the upper currents to high latitudes, and there employed in heating the earth, then it might to a considerable degree compensate for the absence of warm ocean currents. In such a case land at the equator might be nearly as well adapted as water for raising the temperature of the whole earth. We know very well, however, that the heat carried up by the ascending current at the equator performs little work of this kind, but on the contrary is almost wholly dissipated into the cold stellar space above. Thus instead of warming the globe, this ascending current is in reality a most effectual means of getting rid of the heat received from the sun, and thereby reducing the temperature. Since then the earth loses as well as gains the greater part of her heat in equatorial regions; it is there that the substance best adapted for preventing the dissipation of that heat must be distributed in order to raise the general temperature. Now, of all substances in nature water seems to possess this quality in the highest degree; and being a fluid it is adapted by means of currents to carry the heat which it receives to every region of the globe.

It has been urged as an objection to any ocean-current theory that while it provides the requisite amount of heat, it fails to remove the three or four months' darkness of an Arctic winter, which must have proved fatal to plants of the Miocene period. This objection seems, however, to have no foundation in fact. Sir Joseph Hooker stated to the Royal Society at the close of the reading of Mr. George Darwin's paper that palms and other plants brought from the tropics survived the winter in St. Petersburg without damage, though matted down in absolute darkness for more than six months. And he was of opinion that the want of sunlight during the Arctic winter would not be very prejudicial to the plants.

But a cause must be found as well for the cold of the Glacial Epoch as for the warm climate of the Arctic regions that obtained in Miocene times. According to Lyell the continents would require to be moved to high temperate and polar regions to bring about a glacial condition of things in Britain. But this is an assumption which the present state of geological science will hardly admit. It is perfectly certain that there have been no such vast revolutions in physical geography in post-Tertiary times.

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According to others, elevation of the land in the regions glaciated is assigned as the cause of that glaciation, and if the ice had been merely local, such an explanation might have sufficed. But we know the whole Northern Hemisphere down to tolerably low latitudes has been subjected in post-Tertiary times to the rigour of an Arctic climate; so that according to this theory we must assume an upheaval of the entire hemisphere—an assumption too monstrous to be admitted and as useless as absurd.

But I deny of other personal misbelief

Tendency in Geology to Cataclysmic Theories.—There has always been in Geology a tendency to cataclysmic theories of causation; a proneness to attribute the grand changes experienced by the earth's crust to extraordinary causes. Geologists have only slowly become convinced that those changes were the effects of the ordinary agencies

in daily operation around us. For example, hills were formerly supposed to be due to sudden eruptions and upheavals; valleys to subsidences, and deep river gorges to violent dislocations of the earth. All this is now changed, and geologists in general have become convinced that the main features of the earth's surface owe their existence to the silent, gentle, and continuous working of such influences as rain and rivers, heat and cold, frost and snow.

It is not difficult to understand why a belief in cataclysms should so long have prevailed, and geologists should have been so prone to assume the existence of extraordinary causes acting with great force. Geological phenomena come directly under the eye in all their magnitude, and consequently produce a powerful impression on the mind. The quiet and gentle operations of nature's ordinary agencies appear utterly inadequate to produce results so stupendous; and one naturally refers effects so striking to extraordinary causes. Beholding in a moment the effect, we forget that the cause has been in operation for countless ages.

We look for example at a gorge, perhaps a thousand feet in depth, with a small streamlet running along its bottom. Our first impression is that this enormous chasm has been formed by some earthquake or other convulsion of nature rending the rocks asunder. And it is only when we examine the chasm more minutely, and find that it has been actually excavated out of the solid rock, that we begin to see that the work has been done by running water. At first, however, we do not imagine that such a chasm can have been made by the streamlet in its present puny form. We conclude that in former ages a great river ran down the channel. We fail to give the element of time due influence in our speculations. We overlook the fact that the streamlet has been deepening its bed for perhaps millions of years. Why, London itself might have been built by one man had he been at work during all the time that the streamlet was cutting out its gorge! When such considerations cross the mind, every difficulty vanishes, and we feel satisfied that all the work has been performed by the streamlet.

The very same may be said in regard to the origin of hills, valleys, and other features of the earth's surface. Yet how difficult it is still to convince some geologists that our mountains have been formed, as a rule, not by eruptions and upheavals, but by the slow process of subaerial denudation.

Cataclysmic explanations of phenomena have to a large extent disappeared from the field of physical geology. But there is one department in which they still monopolize the field; viz. in that which treats of great climatic changes in former ages. Just as in physical geology great and imposing effects have been attributed to extraordinary causes, so in questions of geological climate vast vicissitudes have been referred to equally vast and unusual agencies.

We know that at a period comparatively recent almost the entire Northern hemisphere down to tolerably low latitudes was buried under snow and ice, the climate being perhaps as rigorous as that of Greenland at the present day. And we know further that at other

I know from personal observation that there is no evidence of any such state of things generally.

periods, Greenland and the Arctic regions were not only to a large extent at least free from ice, but also enjoyed a climate as warm and genial as that of England. To attribute results so striking and stupendous to such commonplace agencies as ocean currents, winds, clouds, and aqueous vapour is at present considered to be little else than absurd. Extraordinary and imposing causes proportionate to the effects are therefore sought.

To account for the Glacial Epoch, for example, the land was at one time supposed to have stood much higher than at present. It was soon discovered, however, that the glaciation was much too general to be explained by such means. Others believed that it might be accounted for by assuming a displacement of the continents, but this hypothesis had likewise to be abandoned when it became known that no alteration in the position of our continents and ocean basins has taken place since the Glacial Epoch.

Others again imagined that some great change had probably taken place in the obliquity of the ecliptic so as to bring the Arctic circle down to beyond the latitude of England. And in order to bring this about what enormous upheavals were supposed to have occurred! It was soon, however, shown that no possible rearrangement of matter on our globe could materially affect the obliquity; and besides this, it was further pointed out that even supposing the Arctic circle was by such means to be shifted down to our latitude, yet it would not bring an Arctic climate along with it but the reverse. This hypothesis being in its turn abandoned, it was next assumed that the earth's axis of rotation must have been moved so as to carry our island up to the Arctic regions. But to shift the axis of rotation even so much as 3°, upheavals and subsidences of a magnitude hitherto unheard of in geological speculations had to be assumed. A change of 3°, however, being totally inadequate to account for the great changes of climate in question, earthquakes of sufficient power to break up the solid framework of the globe had to be called into operation, so as to cause a rearrangement of matter sufficient to produce a displacement of the pole to the extent required. The amount of distortion necessitated by this theory is so enormous that most of its advocates have recently abandoned it as hopeless.

But is there really after all any necessity for invoking the aid of agencies so extraordinary and gigantic? To carve a country, say like Scotland, out of hard Silurian rock into hill and dale and mountain ridges, thousands of feet in height, is certainly a more stupendous undertaking than simply to cover the same area with a sheet of ice. And if commonplace agencies like rain and rivers, frost and snow, can do the former, why may not such agencies as ocean currents, winds, clouds, and aqueous vapour, be sufficient for the latter?

That geological climate should depend on the causes to which we refer cannot appear more improbable to the geologists of the present day than the inference that hills and valleys were formed by atmospheric agencies did to the geologists of the last generation. And there is little doubt that by the next generation the one conclusion will be as freely admitted as the other.

When a physicist so eminent as Sir William Thomson expresses his decided opinion that the agencies in question are all that are necessary to remove the ice from the Arctic regions, and confer on them a mild and temperate climate, it is to be hoped that the day is not far distant when the climate controversy will be concluded. When the fact comes to be generally admitted by physicists that a great *increase* in the temperature and volume of the ocean currents flowing polewards is sufficient to prevent the accumulation of ice in the Arctic regions, it will then be allowed that we only require a great *decrease* in the volume and temperature of the currents in order to account for the former accumulations of ice on the temperate regions, or, in other words, to explain the occurrence of the Glacial Epoch. And when this position is reached, it will be seen that the whole depends upon a very simple cause, requiring neither the submergence nor the elevation of continents, nor any other great change in the physical geography of the globe.

When the excentricity of the earth's orbit is at a high value and the Northern winter solstice is in perihelion, agencies are brought into operation which make the S.E. trade winds stronger than the N.E., and compel them to blow over upon the Northern hemisphere as far probably as the Tropic of Cancer. The result is that all the great equatorial currents of the ocean are impelled into the Northern hemisphere, which thus, in consequence of the immense accumulation of warm water, has its temperature raised, and snow and ice to a great extent must then disappear from the Arctic regions. When the precession of the equinoxes brings round the winter solstice to aphelion, the condition of things on the two hemispheres is reversed, and the N.E. trades then blow over upon the southern hemisphere, carrying the great equatorial currents along with them. The warm water being thus wholly withdrawn from the Northern hemisphere, its temperature sinks enormously, and snow and ice begin to accumulate in temperate regions. The amount of precipitation in the form of snow in temperate regions is at the same time enormously increased by the excess of the evaporation in low latitudes resulting from the nearness of the sun in perihelion during summer.

The final result to which we are, therefore, led, is, that those warm and cold periods, which have alternately prevailed during past ages, are simply the great secular summers and winters of our globe, depending as truly as the annual ones do upon planetary motions, and like them also fulfilling some important ends in the economy of Nature.

I simply deny that there is any geological evidence of general warm and cold periods, & go in for the present state of things and Continuity

Dec 20 1878. J.P.

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